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(71) Applicant (*for all designated States except US*): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): SCHÜTTE, Thorsten [SE/SE]; Bangatan 5 B, S-722 28 Västerås (SE). SASSE, Christian [DE/SE]; Drottninggatan 4 B, S-724 64 Västerås (SE). FROMM, Udo [DE/SE]; Liegatan 33, S-724 67 Västerås (SE).

(74) Agents: KARLSSON, Leif et al.; L.A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).

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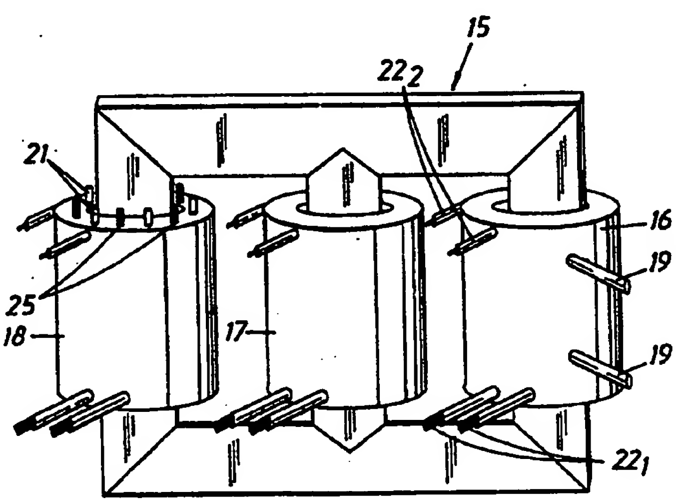

(57) Abstract

The invention is related to a transformer/reactor for high voltage comprising at least one winding. The invention is characterized by the winding being provided by means of an insulated electric conductor (60) comprising at least a current-carrying conductor (61) and furthermore comprising a first layer (62) having semiconducting properties arranged around the current-carrying conductor, a solid insulation layer (63) arranged around said first layer, and a second layer (64) having semiconducting properties arranged around the insulation layer, and furthermore that at least a part of the winding is embedded in a casting material. The invention in addition relates to a method for manufacturing such a transformer/reactor, and to a pre-manufactured winding module.

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A TRANSFORMER/REACTOR AND A METHOD FOR MANUFACTURE OF A TRANSFORMER/REACTOR

The present invention relates to a transformer/reactor comprising at least one winding, as defined in the preamble of Claim 1.

The present invention also relates to a method for manufacturing a transformer/reactor as defined in the preamble of Claim 57, and a premanufactured winding module as defined in Claim 67.

Transformers are used for all transmission and distribution of electric energy, and their task is to allow the exchange of electric energy between two or more electric systems. Transformers are available in all power ranges from a few W up to the 1000 MW range. The designation power transformers refers normally to transformers having a rated output ranging from a few hundred kW to over 1000 MW, and rated voltages ranging from 3-4 kV up to very high transmission voltages.

A conventional power transformer comprises a transformer core, referred to below as core, made of laminated oriented sheets, usually of silicon iron. The core consists of a number of core legs connected by a yoke. Around the core legs there are a number of windings which are normally referred to as primary, secondary and regulation winding. As far as power transformers are concerned these windings are practically always concentrically arranged and distributed along the length of the core leg.

Conventional power transformers for the lower end of the aforementioned power range, are sometimes manufactured having air-cooling in order to remove the inevitable losses in the form of heat. Most conventional power transformers are however oil-cooled and then as a rule by means of so-called forced oil-cooling. This applies especially to high-power transformers. Oil-cooled transformers present a number of known disadvantages. They are among other things large, clumsy and heavy contributing to great transport problems. Extensive requirements need also to be met with regard to security and surrounding equipment, of which the requirement for an outer tank is especially noteworthy in which the transformer is to be contained in the event of oil-cooling.

With respect to reactors, they are not intended for the transmission of energy between the windings but instead intended to create an inductance. Moreover, that which is stated in the aforementioned about transformers is on the whole also relevant with respect to reactors. It is especially noteworthy that large reactors are also oil-cooled.

It is g n rally known that in a dry, oil free transformer or reactor th windings, of the conventional type, are embedded by casting in an organic resin or plastic insulation, normally epoxy resin. The disadvantage of these transformers is that they have a limited rated voltage and power range. The maximum rated output and voltage are normally of the order of 25 MVA and 36 kV respectively. This is primarily due to the heat flux being limited through the dense solid insulation through its low thermal conductivity, which leads to limitations concerning heat, and partly due to electrical restrictions as solid cast resins produces a more inferior insulation for high voltage compared to for example transformer oil, and the combination of conductors insulated in paper and pressboard barriers. It has also other disadvantages, for example the material being inflammable and having consequently to be treated against that etc.

It is known, as disclosed in the US patent document 1,481,585, to embed windings by casting in concrete. The winding in this case is designed of a so called high voltage cable of which the core is insulated by means of impregnated paper or a lacquered or varnished textile material and where the cable is lead-covered. A cable in accordance with this patent, besides which was submitted in 1919, with this stated type of insulation and a fairly rigid metallic screen is not able in practice to comply with the radii of curvature and the bending forces needed in transformer windings. The risk of damages with subsequent puncture arising in the insulation are large. Thermal variations (thermal expansion) and other mechanical forces may easily give rise to cavities in the insulation, which is a starting point for electric breakdown, either taking place immediately or after the effect of partial discharge in the gas volume. Besides, the designation high voltage at the time approximately concerned a voltage of a few tens of kV and a rated output of a few MVA, and the described cable is therefore not suited for the voltage and power levels which high voltage involves in the present situation.

The object of the present invention is to obtain a transformer, alternatively a reactor, avoiding some of the disadvantages of the aforementioned traditionally constructed power transformers/reactors, and to also obtain a method of manufacturing such a transformer/reactor. The transformer/reactor should be used at high voltages, referring to electric voltages, which primarily exceed 10 kV. A typical operating range of a transformer/reactor according to the present invention may be 36 - 800 kV, preferably 72,5 - 800 kV, and possibly higher.

The aforementioned object is achieved by means of a transformer/reactor as defined in the preamble of Claim 1 and which is provided with the advantageous features described in the charact rizing part of th Claim, and by means of a method in accordance with Claim 57.

In a power transform r/reactor according to the inv ntion the windings are preferably of a type corresponding to cables having solid extruded insulation, used presently for power distribution, such as so-called XLPE-cables or cables having EPR-insulation. Such a cable comprises an inner conductor composed of one or several strand parts, the conductor being surrounded by an inner semiconducting layer, the semiconducting layer being surrounded by a solid insulation layer and the insulation layer being surrounded by an outer semiconducting layer. Such cables are flexible, which is an important property in this context since the technology for the device, according to the invention, is based primarily on winding systems in which the winding is formed from a cable which is bent during assembly in a number of turns. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is thus used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The windings in the present invention are constructed such as to retain their properties even when they are bent and when they are subjected to thermal or mechanical stress during operation. It is vital in this context that the layers of the cable retain their adhesion to each other. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for example, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed therein. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in the radius in the cable and, thanks to the comparatively slight differences between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion may take place without the adhesion between the layers being lost.

The material combinations in the aforementioned should only be considered as examples. Other combinations fulfilling the specified conditions and in addition the condition of being semiconducting, i.e., having a resistivity within the range of 10^{-1}-10^{6} ohm·cm, e.g. 1-500 ohm·cm, or 10-200 ohm·cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutyl ne (PB), polymethyl pentene ("TPX"),

cross-link d materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but having particles of conducting material such as soot or metal powder mixed therein.

The mechanical properties of these materials, particularly their coefficient of thermal expansion, are affected relatively little by whether soot or metal powder is or is not mixed therein, at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficient of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate-copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of materials are used as a base in the respective layers, it is desirable for their coefficient of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers do not become detached from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Thus, a transformer/reactor for high voltage comprises at least one winding, which winding is designed having an insulated electric conductor comprising

at least one current carrying conductor, and further comprising a first layer having semiconducting properties arranged so as to surround the current carrying conductor, a solid insulation layer arranged so as to surround said first layer, and a second layer having semiconducting properties arranged so as to surround the insulation layer, and that at least a part of the winding is cast in a casting material.

By providing the transformer/reactor with a winding in accordance with Claim 1 the essential advantage is achieved, namely confining essentially the whole generated electric field within the solid insulation layer in at least one winding turn. This results in that the electric field will be close to zero on the outside of the winding and that the electric field does thus not need to be controlled on the outside of the winding. This means that no field concentrations are obtained on the outside of the winding and that the casting material can be choosen without having to consider an electrical field . Also, reinforcement elements and cooling ducts can be embedded in the casting material without having to consider an electrical field.

According to a particularly advantageous embodiment, the casting material is an essentially inorganic material. By casting at least a part of the winding in an essentially inorganic material a number of advantages are obtained. Given examples are high thermal conductivity and specific heat capacity, effective cooling, incombustibility, low prices, environmental friendliness, god resistance against overheating. Regarding examples of inorganic casting materials, in principle all material masses are possible which may be cast in some conceivable way and which thereafter solidify, as a rule comprising the binding agent itself which solidifies, due to physical and/or chemical mechanisms, for example cement and water, and a filler, for example sand. Examples of fillers are ordinary Portland cement, special cement having a higher mechanical resistance or rapid solidification etc., such as aluminate cement, plaster, the special concrete referred to below which is carbon dioxide hardened.

Alternatively, at least a part of the winding may be cast in an essentially organic material, such as epoxy resin. The aforementioned drawbacks of epoxy resin cast transformer/reactors with conventional windings can be avoided with a transformer/reactor according to the invention as the epoxy resin will not experience any electric stress, and as cooling ducts easily can be embedded in the casting material.

Other advantages and characteristics will become evident in the dependent claims.

Th high voltag insulated electric conductor, according to the invention, may be designed in several advantageous ways. A given advantageous feature is that the insulated conductor is a cable, preferably a high voltage cable.

The insulated conductor or cable, according to a preferred embodiment, is flexible or pliant and said layers are in contact with each other. It is of importance that the cable is flexible in order that it may be used as winding. The insulation layer is advantageously formed of a solid dielectric and preferably made of a polymer material. Furthermore, the first semiconducting layer is primarily on the same potential as the current carrying conductor. The second semiconducting layer is preferably arranged so that it essentially forms an equipotential surface surrounding the current carrying conductor/conductors and the insulation layer, and it is also connected to a predetermined potential, preferably earth potential. The second semiconducting layer, according to an especially advantageous feature, is earthed at or in the vicinity of both ends of each winding and yte another point between both ends is directly earthed.

According to another feature where at least two adjacent layers have essentially the same thermal coefficient of expansion, the current-carrying conductor may comprise a plurality of strands, only a few of said strands being uninsulated with respect to each other.

Each of these three layers, i.e. the two semiconducting layers and the insulation layer, may furthermore be solidly connected to the adjacent layer along essentially the whole connecting surface. The layers, according to an especially important feature, are arranged to adhere to each other also when the insulated conductor or cable is bent. It may finally be noted that it preferably has a diameter within the interval 20-250 mm and a conductor area within the interval 80-3000 mm^2.

The insulated conductor or high voltage cable, utilized in the present invention is flexible and may preferably be of the type described in more detail in the PCT applications WO 97/45919 and WO 97/45847. Additional descriptions of a suitable insulated conductor or cable are disclosed in the PCT applications WO 97/45918, WO 97/45930 and WO 97/45931.

The use of such a cable has the advantage that those regions of a transformer/reactor which are subjected to high electric stress are confined to the solid insulation of the cable. Remaining parts of the transformer/reactor, with respect to high voltage, are only subjected to very moderate electric field strengths. Furthermore, the use of such a cable eliminates several problem areas described under th background of the invention. The insulation as a wh l bec mes very simple. Th time of construction is considerably shorter compared to that of a conven-

tional power transformer/reactor. The windings may b manufactured separately and the power transformer/reactor may be finally assembled on site.

However, the use of such a cable presents new problems, which must be solved. The outer semiconducting layer must be directly earthed at or in the vicinity of both ends of the cable so that the electric stress which arises, both during normal operating voltage and during transient progress, will primarily stress only the solid insulation of the cable. The outer semiconducting layer and these direct earthings together form a closed circuit in which a current is induced during operation. The resistivity of the layer must be high enough so that the resistive losses arising in the layer are negligible.

A capacitive current, besides this magnetically induced current, will flow into the layer due to direct earthing at the ends of the cable. Should the resistivity of the layer be too high then the capacitive current will become so limited that the potential in parts of the layer, during a period of alternating voltage, may differ to such an extent from the earth potential that regions of the power transformer/reactor other than the solid insulation will be subjected to electric stress. By directly earthing several points of the semiconducting layer, preferably one point per turn of the winding, the whole outer layer remains at earth potential and the elimination of the aforementioned is ensured if the conductivity of the layer is high enough.

This one point earthing per turn of the outer screen may be performed in such a way that the earth points rest on a generatrix to a winding and that points along the axial length of the winding are electrically directly connected to a conducting earth bar which is connected thereafter to the common earth potential.

Ideally, since there is such a high resistivity in the outer layer, several earth points turn are required in order to keep the losses as low as possible. Each turn of a winding is provided with an optional, yet consistent for each turn, number of earthing points for the outer layer. The earthing points may rest on a generatrix to the winding, similar to the aforementioned one point earthing, and the points along the axial length of the winding are directly connected to conducting earth bars which are connected thereafter to the common earth potential. However, this presumes that the selection of earth points is performed in such a way that currents are not induced magnetically in the connections to the earth bars. In order to ensure this the connections between earth points and earth bars, in a preferable embodiment, must go through the core or yoke.

In extreme cases the windings may be subjected to such rapid transient ov rvoltage that parts of the uter s miconducting layer assume such a potential that areas of th power transformer other than th insulation of th cabl are sub-

jected to undesirable lectric stress. In order to prev nt such a situation from arising a number of non-linear elements, e.g. spark gaps, phanotrons, Zener-diodes or varistors are connected in between the layer and earth for each turn of the winding. In addition, by connecting a capacitor between the outer insulation layer and earth non-desirable electric stresses are prevented. A capacitor reduces the voltage also at 50 Hz. This earthing principle will be referred to below as "indirect earthing".

The individually earthed earthing tracks are connected to earth via either:

1) A non-linear element, e.g. a spark gap or a phanotron,
2) A linear element parallel to a capacitor,
3) A capacitor

or a combination of all these alternatives.

An advantageous embodiment of the power transformer/reactor is obtained, in accordance with the invention, if said inorganic casting material is a non-conducting casting material.

An advantageous embodiment of the power transformer/reactor is obtained, in accordance with the invention, if the relative permittivity of the casting material, ε, is relatively low, where ε is preferably ≤ 10.

A further advantageous embodiment of the power transformer/reactor is obtained, in accordance with the invention, if the relative permittivity of the casting material, ε, is relatively high, where ε is preferably >10.

It is in connection with this, an advantage if the second semiconducting layer is earthed at or in the vicinity of both ends of each winding and that an additional point between both these end is directly earthed.

A still further advantageous embodiment of the power transformer/reactor is obtained, in accordance with the invention, if said casting material is a weakly conducting casting material.

It is stated, in accordance with an especially advantageous feature of the present invention, that the substantially inorganic casting material is electrically conducting, preferably only weakly electrically conducting. It has preferably a specific resistivity, ρ, between 1 and 100 000 Ωm, preferably between 10 and 10 000 Ωm. This allows for a simple and evenly distributed earthing.

The casting material, in accordance with a preferred embodiment, comprises concrete. A number of advantages are obtained by using concrete for embedment of the winding. Concrete is thus inexpensive compared to the organic resins in known technique and simple to manufacture. If required, embedment of the winding may be undertaken in a simpl way at the construction site.

Concrete also proves to b excell nt in mechanical resistance and rigidity. A transformer/reactor having a winding embedded in concrete may resist high short-circuiting forces, be earthquake-proof, exhibit good acoustical properties and may be made self-supporting. The transformer/reactor, in accordance with the present invention, may furthermore be provided with ducts for cooling, for example water cooling, already during casting.

Still additional advantages that may be mentioned are that a transformer/reactor, in accordance with the present invention, has a higher thermal conductivity and a higher specific heat capacity, which is especially important in order to withstand overloading.

Another notable advantage, in itself not insignificant, is that the transformer/reactor, other than the insulation and semiconducting layers of the conductor, does not contain any oxidizable substances or components which is why it can, practically speaking, not burn or explode.

Examples of concrete which is electrically conducting are disclosed in M. Judge: "Our flexible friend", New Scientist, 10 May 1997, pages 44 - 48, and in "Canadians create conductive concrete", Science, Vol. 276, 23 May 1997, page 1201. The winding may be directly earthed via the concrete by adapting the electrical conductivity of the concrete without producing a short-circuiting via the concrete. The concrete described in the first-named article is a concrete which sets by means of a super critical carbon dioxide and which is especially suitable due to an improved mechanical resistance and complete setting ability. It has the added advantage of having the option of being manufactured having a lower specific weight than the usual concrete.

The casting material, in accordance with an advantageous feature, contains at least one filler, which may either be organic or inorganic. If the filler is organic then it should however only occur in small amounts. For high performance concrete it may for example concern small amounts of agents in the form of organic emulsifiers or acrylic emulsions such as mentioned in M. Tamai and K. Yamaguchi: "Properties of High Polymer Cement Mortar", Science Technology in Japan, vol.63, 1977, pages 7 - 11, or in Y. Ohama, K. Demura and T. Uchyama: "Weatherability of polymer-modified mortars after ten-year outdoor exposure in Koriyama and Sapporo", page 63 of the same publication.

The filler may with advantage comprise an electrically conducting material by means of which the casting material becomes electrically conducting.

An advantageous embodiment of the power transformer/reactor is obtained, in accordance with the invention, if the relative permittivity of the electrically conducting casting material, ε, is relatively low, where ε is preferably ≤ 10.

A further advantageous mbodim nt of th power transformer/reactor is obtained, in accordance with the invention, if the relative permittivity of the electrically conducting casting material, ε, is relatively high, where ε is preferably > 10.

In accordance with another preferred embodiment the transformer/reactor is characterized in that said casting material is provided with n, where n≥2, electrically conducting means, which are each directly earthed, whereby electrical conduction is produced between the respective second semiconducting layer in the winding and said electric conducting means.

Another advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if n points (n≥2) are directly earthed, at least at one turn of at least one winding.

In this context it is an advantage if the n directly earthed points are earthed in such a way that the electric connections between the n earthing points divide the magnetic flux into n parts in order to limit the losses due to earthing.

A further advantage in this relation is if, where the windings surround a cross-sectional area A and the circumference of each winding turn has the length l, then the electric connections between the n earthing points divide said cross-sectional area A into n partial areas $A_1, A_2, \ldots, A_n$ so that

$$A=\sum_{i=1}^{n} A_i$$

and divide said lengths l into n segments $l_1, l_2, \ldots, l_n$ so that

$$l=\sum_{i=1}^{n} l_i$$

and the electric connections between the n earthing points are arranged in such a way that the ends of each segment l_i are electrically connected so that only the partial area A_i is surrounded by a loop consisting of the electric connection and segment l_i and the condition

$$\frac{\phi_i}{\phi}=\frac{l_i}{l}$$

is met, in which ϕ_i is the magnetic flux flowing through the partial area A_i.

A further advantage related to this is, since the flux density B is constant over the total cross-sectional area, if the electric connections between n earthing points are arranged such that the condition

$$\frac{A_i}{A}=\frac{l_i}{l}$$

is met.

A further advantage in this respect is if th s cond semiconducting layer is indirectly earthed at least at one point between both ends of each winding.

An advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the indirect earthing is performed by means of a capacitor connected between the second semiconducting layer and earth.

A further advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the indirect earthing is performed by means of an element having a non-linear voltage-current characteristic connected between the second semiconducting layer and earth.

A further advantageous embodiment of the power transformer/reactor is obtained in accordance with the invention if the indirect earthing is performed by means of a circuit, connected between the second semiconducting layer and earth, comprising an element having a non-linear voltage-current characteristic and which is connected in parallel to a capacitor.

A further advantage is that the indirect earthing may be performed by means of a combination of the aforementioned alternatives.

A further advantage in this respect is if the element having a non-linear voltage-current characteristic may constitute a spark gap, a phanotron, a Zenerdiode or a varistor.

With respect to the filler, it may as in the aforementioned advantageously comprise an electrically conducting material by means of which the casting material may become electrically conducting. Preferred examples of the added electrically conducting material are carbon fiber, graphite, metal particles, fine granular carbonized coal, or the like.

According to another feature the filler is characterized in that it comprises an agent or material having relatively high relative permittivity (capacitivity), ε, preferably $\varepsilon > 10$. This has the advantage that a capacitive impulse earthing may be obtained. A preferred example of a suitable material is titanium dioxide. The relative permittivity may alternatively be relatively low, preferably $\varepsilon \leq 10$. Examples of fillers may then be gas producing additives such as aluminum powder or pumice, the advantage also being the reduction in density of the concrete and thereby a reduction in the weight of the transformer/reactor.

The filler may with advantage furthermore comprise a material having a high thermal conductivity, for example aluminum oxide. This improves the cooling capacity.

Th filler may, according to another advantageous feature, comprise a material having a high specific heat capacity, for example soap ston . Due to this,

the transformer/reactor may, according to the invention, withstand heavy temporary overloading without getting damaged.

According to another advantageous feature the casting material comprises reinforcement elements, i.e. structures of which the function corresponds to the function of the reinforcement bars in normal reinforced concrete, which function is principally to absorb tensile stress. These reinforcement elements may be electrically conducting for example in the form of a construction in stainless steel or another metal, which is preferably not magnetisable. These means may then with advantage be used simultaneously for connection to earth potential. These means may also be designed as hollow constructions, preferably pipes, simultaneously thereby forming cooling ducts. These elements should not form closed turns around possibly the core/the magnetic flux. According to another preferred embodiment, the reinforcement elements may be characterized in that they are electrically insulating, for example made of glass fibre or glass fibre reinforced plastic. These elements may then be formed as hollow constructions, preferably pipes, whereby cooling ducts may simultaneously be formed.

It shall be noted that the whole transformer/reactor may be embedded in casting material. The whole transformer/reactor being embedded or only a part or the whole winding being embedded may be decided from case to case, which may for example be dependent on the space available.

Alternatively, a part of the winding or the transformer/reactor may be embedded in an inorganic material and a part of the winding or the transformer/reactor may be air cooled or embedded in another material, such as for example the known material epoxy resin.

The invention may be applied to both a transformer/reactor comprising a core made of a material with a higher permeability than air, and to a transformer/reactor without such a core.

The method, in accordance with the present invention, is characterized in that the winding is constructed having an insulated electric conductor comprising at least one current carrying conductor, and further comprising a first layer having semiconducting properties arranged around the current carrying conductor, a solid insulation layer arranged around said first layer and a second layer having semiconducting properties arranged around the insulation layer, and in that at least a part of the winding is embedded in casting material, which is an essentially inorganic material. The method in other respects exhibits features by analogy with the claims with respect to the transformer/reactor.

Finally, the present invention refers to a pre-manufactured winding module comprising a winding and designed for a transform r/reactor for high voltage, in

which winding module at least one part of the winding is embedded in an inorganic casting material, in accordance with any one of the claims with respect to the transformer/reactor.

In conclusion it shall be noted that a transformer/reactor, in accordance with the present invention, has the advantage of being especially suitable for use when the installation is close to housing areas, offices, places subjected to the risk of an explosion, areas subjected to earthquakes etc., since the aforementioned is silent-running, explosion-proof, vandalism-proof, and earthquake-proof.

In order to increase the understanding of the invention, it will now be described in more detail, with reference to the accompanying drawings, illustrating a non-limiting example of a preferred embodiment and in which;

Figure 1 shows a schematic view of a conventional transformer having three windings,

Figure 2 shows a schematic view of a transformer in accordance with an example of an embodiment of the present invention,

Figure 3 shows a schematic view of a transformer in accordance with another embodiment of the present invention,

Figure 4 shows a schematic view of a transformer in accordance with a further embodiment of the present invention,

Figure 5a shows schematically a top view of an embedded winding having earthing means, in accordance with the present invention,

Figure 5b shows a schematic perspective view of the embedded winding in Figure 5a,

Figure 6 shows a schematic view of windings having three earthing points per turn, which windings are comprised in the power transformer/reactor in accordance with the present invention,

Figure 7 shows a perspective view of windings having one direct earthing point and two indirect earthing points per winding turn, which windings are comprised in the power transformer/reactor in accordance with the present invention, and

Figure 8a and 8b respectively, show different means in order to achieve indirect earthing, and

Figure 9 shows a cross-section of an insulated electric conductor, which is suitable for use as winding.

The transformer 1 shown in Figure 1 is a conventional three-phase type comprising a core 2 in the form a yoke and having three windings 3. Figure 2 shows a corresponding transformer 5 where the windings are embedded in a casting material, preferably som typ of concrete. Th embedded windings are

designated by the reference numeral 7, and ach one of th windings is provided with outgoing conductors for low voltage 22_1 and high voltage 22_2 respectively. Each one of the windings shown is separately embedded by casting so that hollow concrete cylinders are formed which are threaded onto the core. This has the advantage that if required only one of the windings with the appertaining embedment needs be exchanged should a local fault or local damage arise.

Figure 3 shows a transformer 10 with an alternative shape of the embedment. All three windings shown have been embedded in one and the same embedment, in the form of a casing 12 having three cylindrical openings for the windings.

The transformer shown in Figure 4 having three embedded windings 16, 17, 18 shows among other things two variants of cooling, where the cooling pipes are embedded in the casting material. The embedded winding 16 shows embedded ducts 19 for radial cooling, whereas the embedded winding 18 shows ducts 21 for axial cooling. The same embedded winding 18 also shows schematically illustrated means for earthing 25. All of these ducts may constitute reinforcement elements.

Figure 5a and 5b shows schematically an example of the earthing of a power transformer/reactor according to the present invention. The transformer/reactor 100, seen from the top in Figure 5a and in perspective in Figure 5b, comprises a core 101, around which at least one winding 102 is arranged. The winding is enclosed in an essentially inorganic casting material, for example concrete 103. There are four electrically conducting means in the form of electrodes 104_1, 104_2, 104_3, 104_4, arranged in the concrete which is weakly electrically conducting, which means are accordingly in contact with the electrically conducting concrete 103. The number of electrically conducting means does not need to be 4. Generally speaking there are n electrically conducting means 104_1, 104_2... 104_n where $n \geq 2$. Conduction is achieved between the second semiconducting layers 64 (compare to Figure 9) and the electrodes 104_1, 104_2, 104_3, 104_4, if the winding/windings are constructed of the aforementioned high voltage cable 60. The concrete may furthermore achieve cooling of the winding/windings. The electrodes 104_1, 104_2, 104_3, 104_4, in this embodiment are directly earthed 110 by means of the electric connections 108_1, 108_2, 108_3, 108_4 (only shown in Figure 5a) in such a way that no closed turns around the core may be formed. The electric connections (conductors) 108_1, 108_2, 108_3, 108_4, in a preferred embodiment, cross the core 101 (indicated only schematically) in such a way that the cross-section area, A of th core 101 (and th reby the magnetic flux Φ) is divided into 4 partial areas A_1-A_4. The losses in the second semiconducting layer 64 (compare to Figure 9) are

kept to a minimum by arthing in the aforemention d way. The problem with respect to cooling and earthing are simultaneously solved if the concrete furthermore has such a tuned conductivity that the induced current in the concrete does not lead to high losses, and that the conductivity is simultaneously sufficient in order to earth the second semiconducting layer of the high voltage cable. The weakly conducting casting material has suitably a specific resistivity, ρ, in the range of between 1 and 100 000 Ωm, preferably between 10 and 10 000 Ω. Reference is made to Figure 6 for further description of the principle for direct earthing.

Moreover, it is of an advantage if the earthing electrodes are arranged as close to the winding as possible, and that they are relatively wide, in order to increase the capacitance between the electrodes and the winding, which facilitates the impulse earthing.

Figure 6 shows a perspective view of windings having three earthing points per turn, which windings are comprised in the power transformer/reactor according to the present invention. A core leg appertaining to the power transformer/reactor, indicated in Figure 6, is designated by the numeral 20. Around the core leg 20 there are arranged two windings $22_1$and 22_2, which are designed of the high voltage cable 60 shown in Figure 9. There are radially arranged spacing means 24_1, 24_2, 24_3, 24_4, 24_5, 24_6, with the aim of keeping the windings 22_1 and 22_2 in place. There are, in the case of Figure 6, six spacing means per winding turn. The outer semiconducting layer is earthed at both ends 26_1, 26_2; 28_1, 28_2 of each winding 22_1; 22_2 (compare to Figure 9). The spacing means 24_1, 24_3, 24_5, which are marked in black, are utilized in order to achieve three eathing points per winding turn. These spacing means 24_1, 24_3, 24_5, are thus connected to the second semiconducting layer of the high voltage cable 10. The spacing means 24_1 is directly connected to a first earthing means 30_1, the spacing means 24_3 is directly connected to a second earthing means 30_2 and the spacing means 24_5 is directly connected to a third earthing means 30_3 at the periphery of the winding 22_2 and along the axial length of the winding 22_2. The earthing means 30_1, 30_2, 30_3 may be consist of earthing bars 30_1, 30_2, 30_3, which are connected to the common earth potential 32. The three earthing means 30_1, 30_2, 30_3 are connected by means of two electric connections 34_1, 34_2 (conductors). The electric connection 34_1 is drawn in a first slot 36_1, arranged in the core leg 20, and connected to the earthing elements 30_2 and 30_3. The electric connection 34_2 is drawn in a second slot 36_2, arranged in the core leg 20, and connected to the earthing elements 30_1 and 30_3. Th slots 36_1 36_2 are arranged such that the cross-sectional area, A, of the core leg 20 (and thereby the magnetic flux Φ) is divided into three partial areas A_1, A_2,

A_3. The cor leg 20 is accordingly divided by the slots 36_1, 36_2 into thre parts 20_1, 20_2, 20_3. This results in that currents are not magnetically induced in connection with the earthing bars. Losses are kept to a minimum in the second semiconducting layer by earthing in the aforementioned way.

Figure 7 shows a perspective view of windings having one direct earthing point and having two indirect earthing points per winding turn, which windings are comprised in a power transformer/reactor according to the present invention. A core leg appertaining to the power transformer/reactor, indicated in Figure 7, is designated by the numeral 20. Around the core leg 20, in this case, there are arranged two windings 22_1 and 22_2, which are designed of the high voltage cable 60 shown in Figure 9. The windings 22_1 and 22_2 are kept in place by means of six spacing means 24_1, 24_2, 24_3, 24_4, 24_5, 24_6 per winding turn. The second semiconducting layer is earthed at both ends 26_1, 26_2; 28_1, 28_2 of each winding 22_1, 22_2 (compare to Figure 9). The spacing means 24_1, 24_3, 24_5, which are marked in black, are utilized in order to achieve one direct and two indirect earthing points per winding turn. The spacing means 24_1 is directly connected to a first earthing means 30_1, the spacing means 24_3 is directly connected to a second earthing means 30_2 and the spacing means 24_5 is directly connected to a third earthing means 30_3. As shown in Figure 7, the earthing means 30_1 is directly connected to earth 36, while the earthing means 30_2, 30_3 are indirectly earthed. The earthing means 30_3 is indirectly earthed by being connected in series to earth via the spark gap 34. The earthing means 30_3 is indirectly earthed by being connected to earth via a circuit in series, comprising a spark gap connected in parallel to a capacitor 40. The spark gaps 34 and 38 are examples of a non-linear element, i.e. an element having non-linear voltage-current characteristic.

Figures 8a and 8b respectively, show different elements in order to achieve earthing. Indirect earthing takes place in Figure 8a by means of a circuit 50 comprising an element 52 having non-linear voltage-current characteristic connected in parallel to a capacitor 54. In this case the element 52 having a non-linear voltage-current characteristic is a spark gap 52. The element 52 may also be a gas filled diode, a Zener-diode or a varistor. Indirect earthing takes place by means of a Zener-diode in Figure 8b.

It may be established in summing up that the aforementioned principles for direct and indirect earthing are practically performed in slightly different ways depending on the properties of the used inorganic casting material. Four different cases are obtained:

- The winding/windings are embedded in a non-conducting inorganic material having low relative permittivity ε. The direct earthing is performed according to Figure 6 and the indirect earthing according to Figure 7.
- The winding/windings are embedded in a non-conducting inorganic material having high relative permittivity ε. The direct earthing is performed according to Figure 6 and the indirect earthing is achieved by the high capacitance to ground through the inorganic material.
- The winding/windings are embedded in a weakly conducting inorganic material having high relative permittivity ε. To start with, electrical conducting means according to Figure 5. The indirect earthing is achieved by the high capacitance to ground through the inorganic material. The direct earthing follows partly the principles shown in Figure 6. As the inorganic material is weakly connecting, special earthing elements 30 as shown in Figure 6 are not needed. Contact to ground is achieved evenly along the length of the cable, between the second/outer semiconducting layer of the cable and the weakly conducting inorganic material. The current subsequently continues towards the electrically conducting means 102 where the current is received and led to earth. However, the electrically conducting means are connected to earth in the manner shown in Figures 5-6.
- The winding/windings are embedded in a weakly conducting inorganic material having low relaitve permittivity ε. Electrically conducting means, according to Figure 5 are also used in this case. The direct earthing follows partly the principle of Figure 6 and the indirect earthing follows partly the principle of Figure 7. The difference is that due to the weakly conducting inorganic material no particular earthing elements 30, as shown in Figures 6 and 7 are needed. Contact to earth is achieved, evenly distributed along the whole cable between the second/outer semiconducting layer and the weakly conducting inorganic material. The current subsequently continues towards the electrically conducting means 102 where the current is received and led to earth. However, the electrically conducting means are connected to indirect earth and to direct earth in the manner shown in Figures 5-7.

It should be emphasized that all the aforementioned earthing methods direct or indirect, through the inorganic material or by separate means, may be combined/occur simultaneously.

Finally a cross-section of a cable is shown in Figure 9 which is especially suited for use as winding in the transformer/reactor according to the invention. The cable 60 compris s at least one current carrying conductor 61, which is surrounded by a first semiconducting layer 62. There is arranged an insulation layer

63 around this first s miconducting lay r, and around the insulation lay r there is arranged in turn a second semiconducting layer 64. The electrical conductor 61 may consist of several strands 65. The three layers are achieved such that that they adhere to each other, also if the cable is bent. The shown cable is flexible and this property is maintained during the length of its life. The cable illustrated in Figure 9 differs from conventional high voltage cables in that the outer mechanically protecting housing and the metal screen normally surrounding such a cable are omitted.

The invention naturally comprises a plurality of variations and modifications within the scope of the appended claims. It is not limited to a transformer/reactor having a core made of a material having a higher permeability than air, such as shown in the figures, but that the core may be omitted. The embedment itself may furthermore be varied in size, form and shape. It should also be stressed that anywhere in the examples where the organic casting material may be replaced by an organic casting material, such a modification shall be regarded as being a part of this invention, and shall also fall within the scope of the invention as defined in the appended claims, when applicable.

CLAIMS

1. A transformer/reactor for high voltage comprising at least one winding, **characterized** in that the winding is provided by means of an insulated electric conductor (60) comprising at least a current-carrying conductor (61) and furthermore comprising a first layer (62) having semiconducting properties arranged to surround the current-carrying conductor, a solid insulation layer (63) arranged to surround said first layer, and a second layer (64) having semiconducting properties arranged to surround the insulation layer, and furthermore that at least a part of the winding is embedded in a casting material.

2. A transformer/reactor according to claim 1, **characterized** in that the casting material is an essentially inorganic material.

3. A transformer/reactor according to any one of the preceding claims, **characterized** in that an electric field generated inside the winding is contained within the winding for at least one winding turn.

4. A transformer/reactor according to any one of the preceding claims, **characterized** in that the insulated conductor consists of a cable, preferably a high voltage cable.

5. A transformer/reactor according to any one of the preceding claims, **characterized** in that the insulated electric conductor is manufactured with a conductor area of between 80 and 3000 mm^2 and with an outer cable diameter of between 20 and 250 mm.

6. A transformer/reactor according to any one of the preceding claims, **characterized** in that the second layer (64) is arranged so that it forms a substantially equipotential surface surrounding the current-carrying conductor/conductors (61).

7. A transformer/reactor according to any of the preceding claims, **characterized** in that at least two adjacent layers have essentially equal coefficients of thermal expansion.

8. A transformer/reactor according to any one of the preceding claims, **characterized** in that the insulat d conductor or cable (60) is fl xible and that ach

one of th three lay rs is solidly connected to the adjacent layer along ssentially the whole connecting surface.

9. A transformer/reactor according to any one of the preceding claims, **characterized** in that the layers are arranged to adhere to each other also when the insulated conductor (60) or cable is bent.

10. A transformer/reactor according to any one of the preceding claims, **characterized** in that said casting material is a non electrically conducting material.

11. A transformer/reactor according to claim 10, **characterized** in that the relative permittivity, ε, of the casting material is relatively low, preferably $\varepsilon \leq 10$.

12. A transformer/reactor according to claim 10, **characterized** in that the relative permittivity, ε, of the casting material is relatively high, preferably $\varepsilon > 10$.

13. A transformer/reactor according to any one of claims 11-12, **characterized** in that the second semiconducting layer is earthed at or in the vicinity of both ends (26_1, 26_2; 28_1, 28_2) of each winding (22_1, 22_2) and that furthermore one point between both ends (26_1, 26_2; 28_1, 28_2) is directly earthed.

14. A transformer/reactor according to any one of claims 1-9, **characterized** in that the casting material is electrically conducting.

15. A transformer/reactor according to claim 14, **characterized** in that the conducting casting material has a specific resistivity, ρ, in the range of between 1 and 100 000 Ωm.

16. A transformer/reactor according to claim 14, **characterized** in that the conducting casting material has a specific resistivity ρ, in the range of between 10 and 10 000 Ωm.

17. A transformer/reactor according to any one of the preceding claims, **characterized** in that the casting material includes concrete.

18. A transformer/reactor according to claim 17, **characterized** in that the concrete is a supercritical carbon dioxide hardened concrete.

19. A transformer/reactor according to any one of the preceding claims, **characterized** in that the casting material contains at least one filler.

20. A transformer/reactor according to claim 19, **characterized** in that the filler comprises an electrically conducting material by means of which the casting material becomes electrically conducting.

21. A transformer/reactor according to any one of the claims 14-20, **characterized** in that the relative permittivity, ε, of the casting material is relatively low, preferably $\varepsilon \leq 10$.

22. A transformer/reactor according to any one of claims 14-20, **characterized** in that the relative permittivity, ε, of the casting material is relatively high, preferably $\varepsilon > 10$.

23. A transformer/reactor according to any one of claims 21-22, **characterized** in that said casting material (103) is provided with n, where $n \geq 2$, electrically conducting means (104_1-104_n), each of said electrical conducting means (104_1-104_n) being directly earthed, whereby electrical conduction is achieved between the respective second semiconducting layers (64) in the winding and said electrically conducting means (104_1-104_n).

24. A transformer/reactor according to claim 13, **characterized** in that at least at one turn of at least one winding (22_1, 22_2) n points ($n \geq 2$) are directly earthed.

25. A transformer/reactor according to any one of claims 23-24, **characterized** in that the n directly earthed points are earthed in such a way that the electrical connections (34_1, 34_2, ..., 34_{n-1}) between the n earthing points divide the magnetic flux into n parts in order to restrict the losses generated by earthing.

26. A transformer/reactor according to claim 25, when dependent on claim 11 or 21, **characterized** in that the second semiconducting layer (64) is indirectly earthed at least at one point between both ends (26_1, 26_2; 28_1, 28_2) of each winding (22_1, 22_2).

27. A transformer/reactor according to claim 26, **characterized** in that the indirect arthing is performed by means of a capacitor connected between the second semiconducting layer (64) and earth.

28. A transformer/reactor according to claim 26, **characterized** in that the indirect earthing is performed by means of an element (34) having a non-linear voltage- current characteristic connected between the second semiconducting layer (64) and earth.

29. A transformer/reactor according to claim 26, **characterized** in that the indirect earthing is performed by means of a circuit (38, 40), connected between the second semiconducting layer (64) and earth, comprising an element (38) having a non-linear voltage-current characteristic and which is connected in parallel to a capacitor (40).

30. A transformer/reactor according to claim 26, **characterized** in that the indirect earthing is performed by means of a combination of the alternatives according to claims 27-29.

31. A transformer/reactor according to any one of claims 28-30, **characterized** in that said elements having a non-linear voltage-current characteristic may be in the form of a spark gap (34, 38, 52), a phanotron, a Zenerdiode (56) or a varistor.

32. A transformer/reactor according to any one of claims 17-31, **characterized** in that the electrically conducting material is carbon fiber, graphite, metal particles, fine granular carbonized coal, or the like.

33. A transformer/reactor according to any one of claims 19-20 or 22-32, **characterized** in that the filler comprises an agent having a relatively high relative permittivity, ε, preferably ε>10.

34. A transformer/reactor according to claim 33, **characterized** in that said means comprises titanium dioxide.

35. A transformer/reactor according to any one of claims 19-21 or 23-32, **characterized** in that the filler comprises an agent having a relatively low relative permittivity, ε, preferably ε≤10.

36. A transformer/reactor according to claim 35, **characterized** in that the filler comprises a gas producing additive such as aluminum powder or pumice.

37. A transformer/reactor according to any one of claims 19-36, **characterized** in that the filler comprises a material having a high thermal conductivity.

38. A transformer/reactor according to claim 37, **characterized** in that the filler comprises aluminum oxide.

39. A transformer/reactor according to any one of claims 19-38, **characterized** in that the filler comprises a material having a high specific heat capacity.

40. A transformer/reactor according to claim 39, **characterized** in that the filler comprises soap stone.

41. A transformer/reactor according to any one of claims 19-40, **characterized** in that the filler comprises small amounts of an organic agent, such as emulsifiers or acrylic emulsions.

42. A transformer/reactor according to any one of the preceding claims, **characterized** in that it comprises reinforcement elements embedded in the casting material.

43. A transformer/reactor according to claim 42, **characterized** in that the reinforcement elements are electrically conducting.

44. A transformer/reactor according to any one of claims 23 or 25-43, when dependent on claim 23, **characterized** in that the said reinforcement elements form the electrically conducting means.

45. A transformer/reactor according to claim 42, **characterized** in that the reinforcement elements are electrically insulating.

46. A transformer/reactor according to any one of claims 42 or 45, **characterized** in that the reinforcement elements also form cooling ducts.

47. A transformer/reactor according to any one of the preceding claims, **characterized** in that said layers in the insulating electric conductor are made of materials with such an lasticity and such a relation betw en their coefficients of thermal xpansion that the volume variations in th layers that occur during operation,

du to temp rature variations, is capable of being absorbed by the lasticity of the materials in such a way that the layers maintain their abutment to each other at those variations in temperature that occur during operation.

48. A transformer/reactor according to claim 47, **characterized** in that the material in the said layers have a high elasticity.

49. A transformer/reactor according to any one of claims 47-48, **characterized** in that each of these semiconducting layers constitutes essentially an equipotential surface.

50. A transformer/reactor according to any one of the preceding claims, **characterized** in that a part of the winding is embedded in an inorganic material and that a part of the winding is embedded in another material or in nothing at all.

51. A transformer/reactor according to any one of claims 1-49, **characterized** in that the essentially whole transformer is embedded in said casting material.

52. A transformer/reactor according to any one of claims 1-50, **characterized** in that a part of the transformer/reactor is embedded in an inorganic material and that a part of the transformer/reactor is embedded in another material or in nothing at all.

53. A transformer/reactor according to any one of the preceding claims, **characterized** in that it comprises a core made of a material having a higher permeability than air.

54. A transformer/reactor according to any one of claims 1-52, **characterized** in that the transformer/reactor is designed without a core made of a material having a higher permeability than air.

55. A transformer/reactor according to claim 1, **characterized** in that the casting material is an essentially organic material.

56. A transformer/reactor according to claim 55, **characterized** in that the casting material is an epoxy resin.

57. A m thod of manufacturing a transform r/reactor for high voltage comprising at least one winding, **characterized** in that the winding is provided by means of an insulated electrical conductor (60) comprising at least one current-carrying conductor (61), and additionally comprising a first layer (62) having semiconducting properties arranged to surround the current-carrying conductor, a solid insulation layer (63) arranged to surround said first layer, and a second layer (64) having semiconducting properties arranged to surround the insulation layer, and that at least a part of the winding is embedded in a casting material.

58. A method of manufacturing a transformer/reactor according to claim 57, **characterized** in that the casting material is an essentially inorganic material.

59. A method of manufacturing a transformer/reactor according to claim 57 or 58, **characterized** in that the winding is designed in accordance with that stated in any one of claims 3-13, 17-20, 24-31, 32-49.

60. A method of manufacturing a transformer/reactor according to any one of claims 57-59, **characterized** in that the casting material is made in accordance with that stated in any one of the claims 3-9, 14-23, 25-31, or 32-49.

61. A method of manufacturing a transformer/reactor according to any one of claims 57-60, **characterized** in that a part of the winding is embedded in an inorganic material and that a part of the winding is embedded in another material or in nothing at all.

62. A method of manufacturing a transformer/reactor according to any one of claims 57-60, **characterized** in that essentially the whole transformer is embedded in casting material.

63. A method of manufacturing a transformer/reactor according to nay one of claims 57- 61, **characterized** in that a part of the transformer/reactor is embedded in an inorganic material and that a part of the transformer/reactor is embedded in another material or in nothing at all.

64. A method according to any one of the preceding claims, **characterized** in that the embedding by casting takes place on site.

65. A method of manufacturing a transformer/reactor according to any one of claims 57-63, **characterized** in that the transformer/reactor is built of pre-manufactured modules comprising embedded winding.

66. A method of manufacturing a transformer/reactor according to claim 57, **characterized** in that the casting material is an essentially organic material.

67. A pre-manufactured winding module comprising a winding and adapted for a transformer/reactor for high voltage, in which winding module at least a part of the winding is embedded in a casting material, in accordance with any one of claims 1-56.

Fig. 1

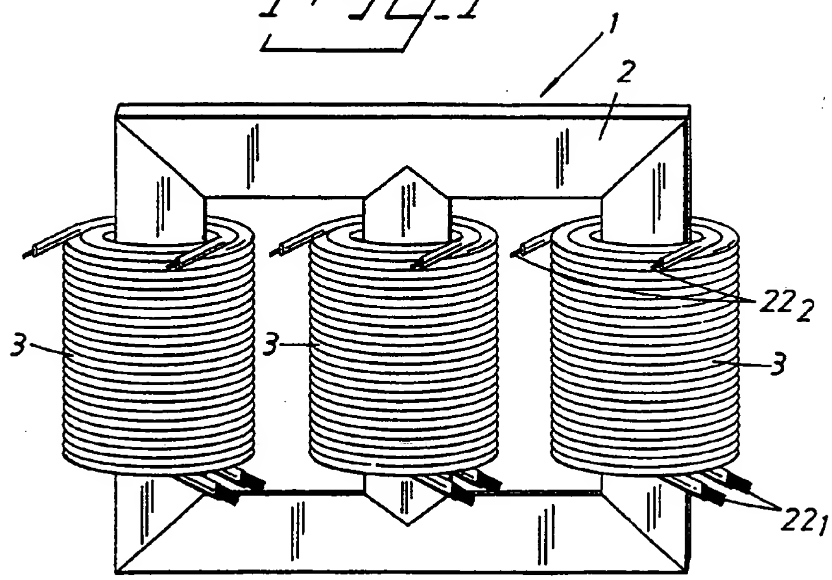

Fig. 2

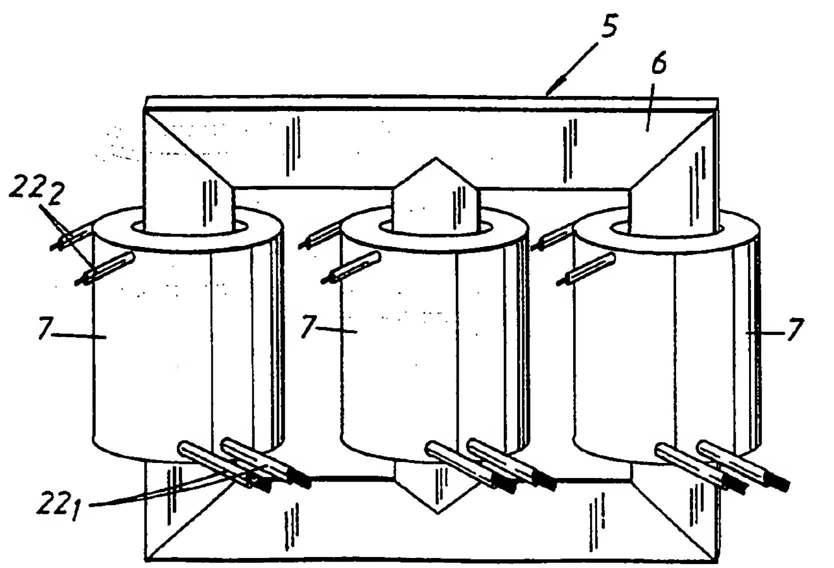

Fig. 3

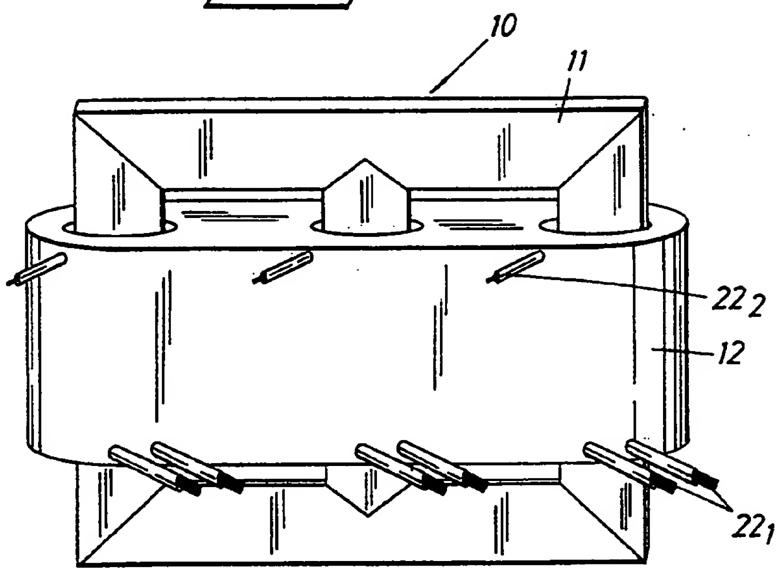

Fig. 4

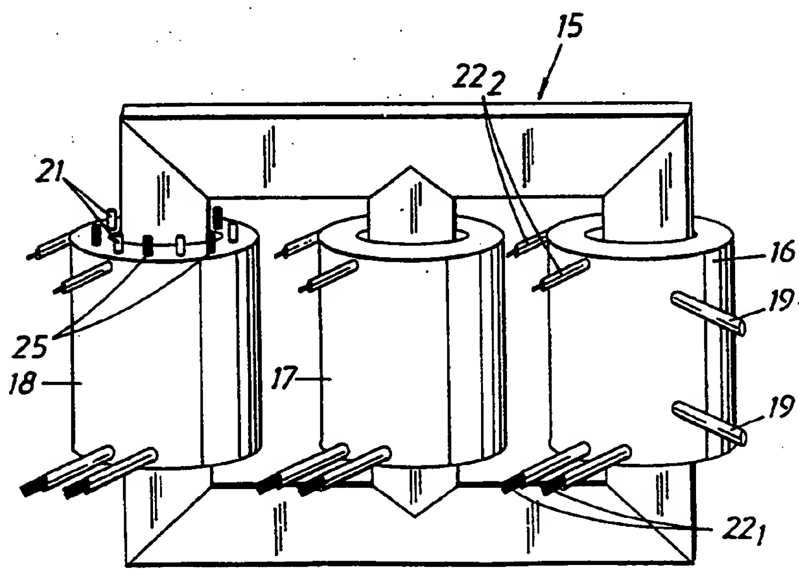

Fig.5a

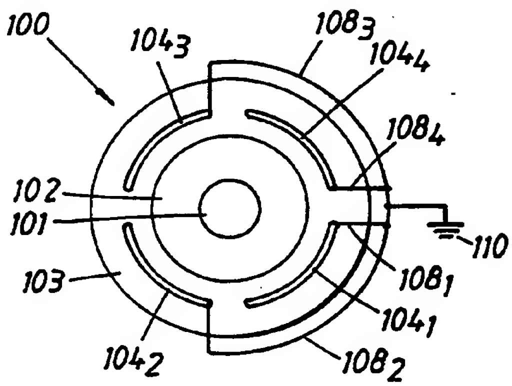

Fig.5b

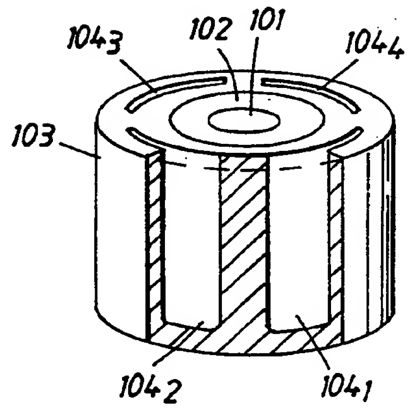

Fig.6

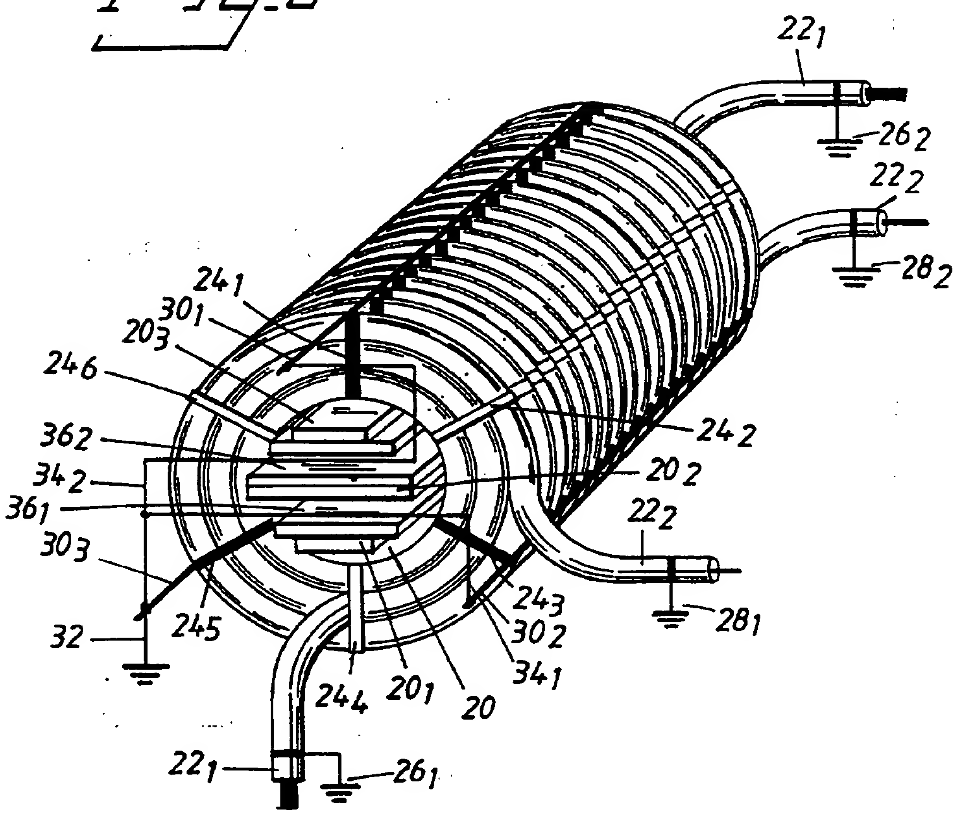

Fig. 7

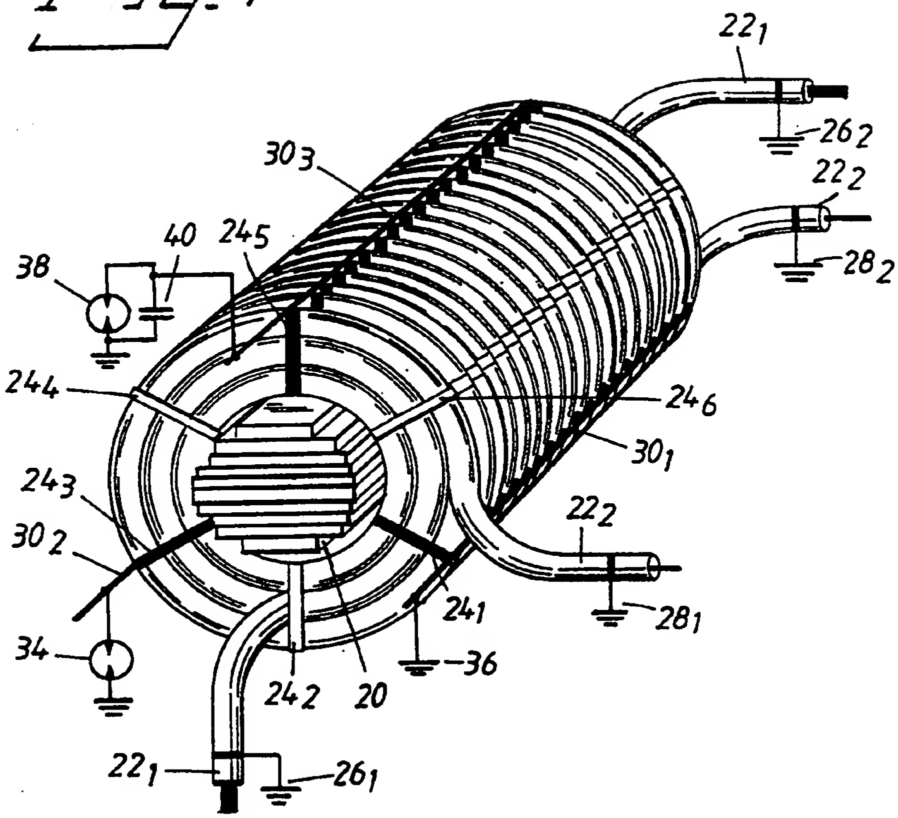
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Fig. 8a

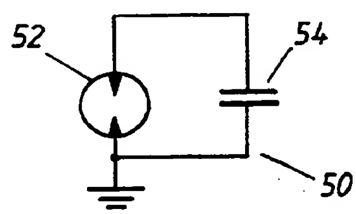

Fig. 8b

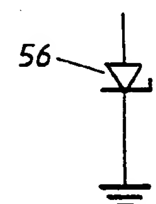

Fig. 9